



PATENT APPLICATION  
(AMENDED Substitute Specification for S/N 10/792,078)  
Docket No. 42085-00031USD2; China Patent Agent Docket No. FPEL04150018US

## **ELIMINATION OF ELECTRIC-POP NOISE IN MR/GMR DEVICE**

### **CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application is a divisional application of U.S. Patent Application Serial No. 10/317,878, filed on December 12, 2002, which is a divisional application of U.S. Patent Application No. 09/265,083, filed on March 9, 1999, now issued as U.S. Patent No. 6,583,971, and is incorporated by reference herein in its entirety.

### **BACKGROUND OF THE INVENTION**

#### Field of the Invention

[0002] The present invention generally relates to an active device capable of converting an electrical signal into a voltage, more specifically, to a magnetic recording head consisting of either an anisotropic magneto-resistive (hereinafter referred as AMR) or giant magneto-resistive (hereafter referred as GMR) sensor along with an insulation spacer and magnetic shields.

#### Description of the Related Art

[0003] As is well known in the field, the insulating spacer in AMR/GMR recording heads is becoming thinner and thinner in order to increase a linear recording density. Inevitably, we are facing electric-pop noise resulting from the thinner spacer. For high manufacturing yield and reliability of electric and magnetic performance, such electric-pop noise must be eliminated.

[0004] US patent No. 3864751 entitled "Induced Bias Magneto-resistive Read Transducer" issued to Beaulier and Napela, on February 4, 1975 proposed that a soft-adjacent magnetic transverse bias layer (hereinafter referred to as "SAL") is isolated from a magneto-resistive device (referred to as "MR" hereinafter). The patent did not reveal any methods how to make it. Another key point is that the MR and SAL are electrically isolated. In the prior art described by Beaulieu et al., electric-pop noise is present if a thinner insulating spacer ( $<150 \text{ \AA}$ ), such as  $\text{Al}_2\text{O}_3$ , is used. Otherwise, the devices would need a thicker SAL to bias the MR if a thicker

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insulator spacer (2-400 Å) were used. There are two problems associated with the latter case. Firstly, the SAL can not be easily saturated by a current in the MR and an antiferromagnetic pinning layer must be used to pin the SAL so that the SAL magnetization is perpendicular to the current direction. In this case, the device process becomes very complicated and it also renders designs less extendible to a narrower shield to shield spacing for higher density recording.

[0005] The SAL has a function as a shunt bias layer in SAL biased AMR devices. When the MR and SAL are spaced by electric conducting materials, such as Ta, the SAL and MR devices have the same electric track width. These configurations have been disclosed in US patent No. 4,663,685 issued in 1987, to C. Tsang, US patent No. 4,639,806 issued in 1987 to T. Kira, T. Miyagachi, and US patent No. 5,108,037 issued to M. Yoshikawa, M. T. Krounbi, O. Voegeli and P. Wang.

**SUMMARY OF THE INVENTION**

[0006] Accordingly, one objective of this invention is to provide an AMR design with a thin insulating spacer free of electric-pop noise.

[0007] Another objective is to provide a SAL biased AMR product using an insulated spacer.

[0008] A further objective of this invention is to provide an electric active device free of electric-pop noise over an insulating spacer on the top of an electric conductor.

[0009] Still another objective of this invention is to provide a design to eliminate electric-pop noise in GMR magnetic recording heads with a thin insulating spacer.

[0010] In accordance with one aspect of the present invention, a magnetic recording device comprising:

- an anisotropic magnetoresistive (MR) sensing layer;
- a soft-adjacent magnetic transverse bias layer (SAL);
- an insulating layer arranged between said magnetoresistive layer and said magnetic transverse bias layer;

conductive layer contacting electrically both said magnetosensitive layer and said magnetic bias layer at at least one end region of said SAL element.

[0011] In accordance with another aspect of the present invention, a magnetic recording device comprising:

- a first shield;
- a second shield;
- a GMR device;
- a first insulating gap layer between said GMR and one of said shields;
- a second insulating gap layer between said GMR and another of said two shields;
- a conductive layer contacting electrically said GMR device to either one of said shields.

[0012] In accordance with one aspect of the present invention, a magnetoresistive device comprising:

- a magnetoresistive layer;
- a soft-adjacent magnetic transverse bias layer (SAL);
- an insulating layer arranged between said magnetoresistive layer and said magnetic transverse bias layer;
- a conductive layer contacting electrically both said magnetoresistive layer and said magnetic bias layer at at least one end region of said SAL element.

[0013] In accordance with a further aspect of the present invention, a hard disk driver is provided with the magnetoresistive device.

[0014] Compared to the prior art by Tsang, Kire et al and Kroumbi et al, this invention provides an AMR sensor with much improved signal. The signal improvement can be as much as 90% provided that the same MR/SAL device and operating current are used for the device.

[0015] Other objects, features and advantages of the present invention will become readily apparent from the following description taken in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF DRAWINGS

[0016] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

[0017] Figure 1a is a diagram of a preferred embodiment of the invention,

[0018] Figure 1b is a cross-section view taken along line AA indicated in Figure 1a,

[0019] Figure 2 is a diagram of an alternative embodiment of the invention,

[0020] ~~Figure 3 shows~~ Figures 3a-3d show electric-pop test results before and after MR and SAL are connected by microfabrication,

[0021] ~~Figure 4 shows~~ Figures 4a-4b show an extension to prevent a GMR device from electric-pop noise due to discharge between the GMR device and shields.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0022] Embodiments according to the present invention will be described in the following.

[0023] Figure 1a is a diagram of a first preferred embodiment of the invention. As shown in this figure, MR layer 10 and SAL 30 are separated by a thin insulated spacer layer 20, and are electrically connected at the ends of the MR element. An active region 10 of the MR device could be either a NiFe film or a composite layer, such as TaN/NiFe/TaN. NiFe, thickness ranges from 50 to 400 Å. Side regions 12 and 14 of the MR element make electric contact with longitudinal bias layer and lead layer stacks 40 and 42. End regions 16 and 18 of the MR element are connected to the end regions 32, 34 of SAL by ~~leads~~ the lead and longitudinal bias layer stacks 40 and 42. The length of MR element and SAL ranges from 2 to 20 μm. Insulating spacing layer 20 is made of insulating materials, such as Al<sub>2</sub>O<sub>3</sub>, AlON and SiO<sub>2</sub>, and the typical thickness of insulating spacing layer 20 varies from 50 to 200 Å. Soft-adjacent layer (SAL) 30

can be made of NiFe, NiFeCr, NiFeRh. The moment ratio of SAL 30 to MR layer 10 ranges from 0.6 to 1.0.

[0024] In Figure 1a, longitudinal bias layer 40 can be made of anti-ferromagnetic materials, such as NiMn, FeMn, PtPdMn, IrMn and PtMn. Lead layer 42 can be made of Ta, W or Ta/Au/Ta. Longitudinal bias layer 40 and lead layer 42 extend coverage on top of the MR element 10 and electrically contact with MR element 10 through side regions 12 and 14, respectively. Therefore, the electric track width of the MR element is defined by active region 10 as longitudinal bias layer 40 and lead layer 42 have much higher electric conductivity than the MR layer.

[0025] On the other hand, longitudinal bias layer 40 and lead layer 42 electrically contact with SAL layer 30 through side surfaces 32 and 34, respectively. Therefore, the electric track width of the SAL element is the entire element width.

[0026] Now refer to FIG. 1b that shows cross-section view taken along line AA indicated in FIG. 1a. Function of insulator films 50 is to prevent electric connection from MR 10 to SAL 30. Numeral 60ABS designates an air-bearing surface (ABS).

[0027] In the following drawings, similar parts to those in Figure 1 are designated by the same numerals as those used in Figure 1. Figure 2 shows an alternative embodiment of the present invention. MR layer 10 and SAL 30 are separated by a thin insulating spacer layer 20. MR layer 10 and SAL 30 are electrically connected at only one end region of the MR element. In this embodiment, no electric current passes through the SAL element. However, the whole SAL element is in an equal electric potential to that of one side of the MR element. One side region of the longitudinal bias layer and the leader layer does not electrically contact with a corresponding SAL end region. Insulator films 52 are electrically connected between MR layer 10 and SAL 30 at one end of the trilayer device.

[0028] Figure 3 shows test results of the electric-pop noise before and after connection of MR layer 10 and SAL 30 under test conditions: trigger level = 75  $\mu$  V, threshold level = (Noise amplitude of  $I_s$  = 5mA) + 60  $\mu$  V, and read current = 12mA.

[0029] Figures 3a and 3b show electric-pop noise spectra of the device before edge shorting of the MR and SAL element, and Figures 3c and 3d show the same of the device after edge shorting of the MR and SAL element.

[0030] Figure 4 shows an extension to prevent a GMR device from electric-pop noise due to discharge between the GMR device and shields.

[0031] Figure 4a is a diagram of a GMR device that is electrically shorted to a bottom shield to prevent electric-pop noise due to static discharge between the GMR device and a bottom shield.

[0032] Figure 4b is a diagram of a GMR device that is electrically shorted to a top shield to prevent electric-pop noise due to static discharge between the GMR device and a top shield.

[0033] In Figures 4a and 4b, reference numeral 60 designates a GMR active device, the GMR device including a spin-valve, GMR multilayer, and spin-dependent tunneling device, and numerals 62 and 64 designate stacks having a longitudinal bias layer and a lead layer, respectively. Electric contact 66 is provided between one side of lead layer 64 and of longitudinal bias layer stack 62 and the bottom shield 70. Bottom and top shields 70 and 80 are made of soft magnetic materials, such as NiFe. Gaps 72 and 74 are filled with electrically insulating materials, such as Al<sub>2</sub>O<sub>3</sub>, AlNO, AlN, and vary from 250 Å to 2000 Å in thickness. Electric contact 68 is provided between one side of lead layer 64 and of longitudinal bias layer stack 64 and top shield 80.

[0034] Operational principle of the present invention is explained as follows.

[0035] Signal amplitude of the AMR device is given by equation:

$$\Delta V_{pp} = MrW * J_{MR} * \frac{\Delta \rho * R_{SAL} * (\sin^2 \theta - \sin^2 \theta_0)}{(R_{MR} + R_{SAL})} \quad (1)$$

where:

- $\Delta V_{pp}$  : peak-to-peak amplitude (V),
- MrW: MR read track width ( $\mu m$ ),
- $J_{MR}$ : current density passing through the MR device film ( $A/m^2$ ),
- $\Delta\rho$ : magnetoresistive coefficient of resistivity of the MR layer ( $\Omega.m$ ),
- $\frac{R_{SAL}}{(R_{MR} + R_{SAL})}$  : voltage shunting factor,
- $R_{MR}$ : sheet resistance of the MR layer ( $\Omega$ ),
- $(R_{MR}+R_{SAL})$ : sheet resistance of the SAL layer ( $\Omega$ ), and
- $(\sin^2\Theta-\sin^2\Theta_0)$ : sensitivity function of the MR device.

[0036] For the same operating current I, there is a signal enhancement by a factor of square of  $(R_{MR}+R_{SAL})/R_{SAL}$  comparing an AMR device without a current flowing through SAL to that with a current shunting through the SAL. In a typical AMR device, the shunt factor  $R_{SAL}/(R_{MR}+R_{SAL})$  is as much as 0.7.

[0037] In the case of a SAL electrically isolated from the MR element, the SAL is electrically floating, which could result in electric-pop noise due to static discharge between the MR and SAL. In the invention illustrated in Figure 1, we let a small percentage of current flow through the SAL. The way to achieve it is to provide electric contact to the SAL at the end of the element. With such configuration, the SAL is no longer electrically floating as there is a small amount of current flowing through the SAL. The shunting factor is determined by equation:

$$\frac{R_{SAL} * L_{SAL}}{R_{MR} * W_{MR} + R_{SAL} * L_{SAL}} \quad (3)$$

where:

$R_{SAL}$ : sheet resistance of the SAL,

$R_{MR}$ : sheet resistance of the MR layer,

$L_{SAL}$ : length of the SAL, and

$W_{MR}$ : electric track width of the MR layer.

[0038] We can tune the current ratio by simply adjusting element height and length. For reference, current MR/SAL sheet resistance ratio is about 3/7. We can get 2% of current flowing through the SAL by setting width of the MR element at 20  $\mu\text{m}$  assuming that our physical read track width is at 1  $\mu\text{m}$ . This shunt ratio renders such a device have much higher signal than that of conventional SAL-biased AMR heads with a conducting spacer.

[0039] An alternative approach taught in Figure 2 is to electrically connect one end of the SAL to the MR element. In this case, the SAL layer keeps the same electrical potential as that of one terminal of the AMR device and is no longer electrically floating. The advantage of this approach is to eliminate the current shunting through the SAL while preventing the SAL from electrically floating. By doing this, we can effectively eliminate charges building up in the SAL so that the electric-pop noise in the MR device is prevented.

[0040] Similar concept is used to short an SV (spin valve) GMR device to either a top or bottom shield. By doing this, we can prevent the electric-pop noise due to static discharge between the GMR device and shields. It must be pointed out that such electric-pop noise is a fundamental technology challenge for future higher density recording.

[0041] Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, and representative devices, shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

## ABSTRACT

The invention relates to a magnetic recording head comprising: a bottom shield; a top shield; an AMR device with MR and SAL separated by a thin insulating layer; a first insulting gap layer between said bottom shield and said AMR; a second insulating gap layer between said AMR and said top shield; a conductive layer contact at one end region of said MR and SAL.

5 Furthermore, magnetic recording heads with GMR device free of electric-pop noise also are disclosed.